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AIR POLLUTION ASPECTS OF ZINC AND ITS COMPOUNDS

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Bethesda, Maryland

September 1969

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AIR POLLUTION ASPECTS
OF
ZINC AND ITS COMPOUNDS

Prepared for the
National Air Pollution Control Administration
Consumer Protection & Environmental Health Service
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September 1969

FOREWORD

As the concern for air quality grows, so does the concern over the less ubiquitous but potentially harmful contaminants that are in our atmosphere. Thirty such pollutants have been identified, and available information has been summarized in a series of reports describing their sources, distribution, effects, and control technology for their abatement.

A total of 27 reports have been prepared covering the 30 pollutants. These reports were developed under contract for the National Air Pollution Control Administration (NAPCA) by Litton Systems, Inc. The complete listing is as follows:

Aeroallergens (pollens)
Aldehydes (includes acrolein
  and formaldehyde)
Ammonia
Arsenic and Its Compounds
Asbestos
Barium and Its Compounds
Beryllium and Its Compounds
Biological Aerosols
  (microorganisms)
Boron and Its Compounds
Cadmium and Its Compounds
Chlorine Gas
Chromium and Its Compounds
  (includes chromic acid)
Ethylene
Hydrochloric Acid
Hydrogen Sulfide
Iron and Its Compounds
Manganese and Its Compounds
Mercury and Its Compounds
Nickel and Its Compounds
Odorous Compounds
Organic Carcinogens
Pesticides
Phosphorus and Its Compounds
Radioactive Substances
Selenium and Its Compounds
Vanadium and Its Compounds
Zinc and Its Compounds

These reports represent current state-of-the-art literature reviews supplemented by discussions with selected knowledgeable individuals both within and outside the Federal Government. They do not however presume to be a synthesis of available information but rather a summary without an attempt to interpret or reconcile conflicting data. The reports are necessarily limited in their discussion of health effects for some pollutants to descriptions of occupational health exposures and animal laboratory studies since only a few epidemiologic studies were available.

Initially these reports were generally intended as internal documents within NAPCA to provide a basis for sound decision-making on program guidance for future research activities and to allow ranking of future activities relating to the development of criteria and control technology documents. However, it is apparent that these reports may also be of significant value to many others in air pollution control, such as State or local air pollution control officials, as a library of information on which to base informed decisions on pollutants to be controlled in their geographic areas. Additionally, these reports may stimulate scientific investigators to pursue research in needed areas. They also provide for the interested citizen readily available information about a given pollutant. Therefore, they are being given wide distribution with the assumption that they will be used with full knowledge of their value and limitations.

This series of reports was compiled and prepared by the Litton personnel listed below:

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ABSTRACT

Zinc and its compounds are generally considered to be nontoxic; however, high concentrations of certain compounds can produce harmful effects on humans, animals, and plants. Zinc is commonly associated with other metals, such as lead, copper, and cadmium, thus making the effects of zinc air pollution difficult to distinguish from the effects caused by its associated metals. Consequently, the specific effects and the synergistic effects of these metals are not yet fully understood. The most common effect of zinc air pollution is the occurrence of "metal-fume fever" which results from the inhalation of zinc oxide fumes. This nonfatal self-limiting illness causes fever, nausea, and aching. Deaths have occurred in humans from accidental exposure to zinc chloride fumes, while cattle and horses have died from inhaling air contaminated with lead and zinc. Laboratory experiments have confirmed the mildly toxic nature of zinc compounds. Limited evidence exists concerning plant damage from high concentrations of zinc dust and fumes; no evidence was found of damage to materials.

Zinc and zinc compounds are emitted into the atmosphere mainly from the refineries producing primary or secondary zinc as a principal product or as a by-product, from the refining of other metals containing zinc as an impurity, in the brass manufacturing process, or in the application of zinc-galvanizing.

Large concentrations of zinc emissions are possible from these sources. Twenty-four-hour-average atmospheric concentrations of zinc in urban areas of the United States have averaged 0.67 $\mu g/m^3$, with an extreme value of 58.00 $\mu g/m^3$ recorded in 1963.

Adequate methods are available for the control of zinc air pollution from the significant pollution sources. The extent to which these methods are employed is not known. No information has been found on the economic costs of zinc air pollution or on the costs of its abatement. Methods are available for determining the atmospheric content of zinc compounds.

CONTENTS

Zinc's and zinc compounds'

FOREWORD

ABSTRACT

1. INTRODUCTION 1

2. EFFECTS 2

2.1 Effects on Humans 2
    2.1.1 Inhalation 2
    2.1.2 Ingestion 6
    2.1.3 Skin Contact 9
2.2 Effects on Animals 10
    2.2.1 Commercial and Domestic Animals . . . 10
    2.2.2 Experimental Animals 10
        2.2.2.1 Inhalation 10
        2.2.2.2 Ingestion 12
        2.2.2.3 Injection 14
2.3 Effects on Plants 16
2.4 Effects on Materials 17
2.5 Environmental Air Standards 17

3. SOURCES 19

3.1 Natural Occurrence 19
3.2 Production Sources 20
    3.2.1 Mining 20
    3.2.2 Smelting and Refining 20
        3.2.2.1 Primary Zinc Production . . . 20
        3.2.2.2 Primary Production of Other Metals 25
        3.2.2.3 Secondary Zinc Refining . . . 28
        3.2.2.4 Secondary Brass and Bronze-Melting Processes 29
3.3 Product Sources 30
    3.3.1 Zinc Galvanizing 30
    3.3.2 Brass Production 31
    3.3.3 Incineration 32
3.4 Environmental Air Concentrations 33

4. ABATEMENT 34

4.1 Primary Zinc Smelting Operations 34
4.2 Secondary Zinc Melting Operations 36
4.3 Galvanizing Operations 38
4.4 Zinc-Alloy Sweating Operations 38
4.5 Secondary Brass Melting Operations 39
4.6 Open-Hearth and Electric-Arc Furnaces, Steel Operations 40
4.7 Effectiveness 41

5. ECONOMICS 42

6. METHODS OF ANALYSIS 43

   6.1 Sampling Methods 43
   6.2 Quantitative Methods 43

7. SUMMARY AND CONCLUSIONS 45

REFERENCES

APPENDIX

LIST OF FIGURES

1. Size Ranges of Zinc in the Atmosphere 7

2. Lung Retention of Inhaled Particles as a Function of Their Size for the Relevant Region 8

3. Trend Curves for Domestic Primary Zinc Production and Slab Zinc Consumption 26

LIST OF TABLES

1. Selected Data on Acute Zinc Toxicity in Experimental Animals 15
2. Zinc Content in Commercially Important Zinc Minerals 19
3. Leading Zinc-Producing Mines in the United States in 1967 in Order of Output 21
4. Mine Production of Recoverable Zinc in the U. S., By States, Listed by Order of Their 1967 Production . . 22
5. Zinc Concentrations at Emission Points of a Zinc Plant (Donora Area, 1948) 24
6. Estimated Atmospheric Pollution 24
7. Zinc Concentrations During Strike and Post-Strike Periods in the Steel Industry in Four Communities (U.S.A., 1956) and Corresponding Probability Levels . 28
8. Dust and Fume Emissions from a Zinc-Sweating Furnace Controlled by a Baghouse 29
9. Analysis of Fumes from Zinc Galvinizing Kettles . . . 31
10. Emissions from Various Types of Brass Furnaces . . . 32
11. Smelting Gas Streams and Dust Burden Before Revision for Filtration of Gases (1951) 36
12. Comparative Data on Hoods Used in Various Types of Furnaces 37
13. Comparative Data on Air Pollution Control Equipment Used in Two Secondary-Zinc Melting Operations 37
14. Reduction of Emissions from Galvinizing and Brass-Melting Operations, Los Angeles County, 1950-1960 . . 41
15. Properties, Toxicity, and Uses of Some Zinc Compounds 58
16. Physicochemical Properties of Zinc 70

LIST OF TABLES (Continued)

17. Primary and Redistilled Secondary Slab Zinc Produced in the U.S. 71

18. Consumption of Zinc in the U.S. 72

19. Manufacturers of Zinc Slab in the U.S., 1968 73

20. Primary Slab Zinc Plants by Group Capacity in the U.S. in 1967 74

21. Secondary Slab Zinc Plants by Group Capacity in the U.S. in 1967 75

22. Concentration of Zinc in the Air 76

1. INTRODUCTION

Although zinc is an essential element of the human and animal body, zinc and its compounds have been found to be toxic under certain conditions. The most common hazards to health are the inhalation of zinc oxide fumes (which produces metal-fume fever) or accidental poisoning resulting from the ingestion of acidic foods prepared in zinc-galvanized containers. Other health hazards include corrosive effects on the skin from zinc salts, irritation and damage to mucous membranes from zinc chloride fumes, and a possible pneumonitis resulting from inhaling zinc stearate.

Zinc and its compounds can be found in the atmospheric environment. The most common sources of zinc emissions are zinc refineries, the brass industry, and zinc-galvanizing processes.

2. EFFECTS

Zinc is generally considered nontoxic to humans, animals, and plants, and produces no known harmful effects on materials. However, in certain forms, zinc is toxic to humans and animals when inhaled or ingested, or when in contact with the skin. The degree of toxicity varies with concentrations, type of compound, and mode of application.

2.1 Effects on Humans

Zinc, essential to all living organisms, is a normal constituent of the human body. It is taken into the body in the diet or by inhalation, and is eliminated by normal processes of excretion and perspiration. When normal intake values are exceeded, zinc poisoning occurs.

The properties, toxicity and uses of zinc compounds are tabulated in the Appendix (Table 15).

2.1.1 Inhalation

Inhalation intake is normally an unimportant source of zinc, except where high concentrations cause excessive amounts of zinc to be added to the body. In this case, normal excretion is not sufficient to discharge the excess, and poisoning from air pollution occurs. This ailment is common to several metals, and the most usual one attributable to zinc poisoning. However, Patty[36] notes that effects attributable to exposure to zinc fumes may in part be caused by cadmium, which occurs uniformly as a contaminant in zinc.

Metal-fume fever as a result of zinc oxide inhalation is a malaria-like illness which lasts approximately 24 hours and is never fatal.[12] The symptoms include fever, malaise and depression, nausea and sometimes vomiting, dryness of the throat, and aching of the head and body. After a few hours, the patient perspires excessively as his temperature and white blood cell count rise; a chill may occur when the temperature reaches 103-104^{o}, followed by a drop to normal temperature. Occasionally, convulsions and mental confusion may occur, as well as albuminuria and glucose in the urine. Measurable effects include reduction in the vital capacity of the lung for as long as 15 hours (in 36 out of 100 cases this condition recurred weekly or even more frequently)[33] and leukocytosis ($12\text{-}16 \times 10^{6}$ leukocytes/cm^{3}).[51] Lehmann[29] postulated that the inhaled zinc fume particles release modified protein into the body, with the subsequent absorption of the modified protein resulting in the characteristic response noted with the injection of a foreign body. A review of metal-fume fever from inhalation of zinc oxide is given by Rohrs in the American Medical Association's Archives of Internal Medicine (1957).[39]

Metal-fume fever is a potential hazard wherever zinc oxide is an industrial product or by-product: zinc smelting, manufacture of zinc oxide and zinc powder, the manufacture of brass, and the welding of galvanized iron. The disease is self-limiting, and its treatment is symptomatic.[58]

Matsui *et al*.[31] studied 66 welders who had been exposed to zinc oxide fumes and dust during electric welding of galvanized iron pipe in the holds of a ship. Half of the welders had been employed in welding for less than 5 years and the remainder for from 5 to 30 years. In 49 of the studied cases the following symptoms were observed, in order of frequency:

1. Fever and chills
2. Arthralgia
3. Myalgia
4. Throat irritation
5. Chest irritation
6. Chest discomfort
7. Vomiting and nausea
8. Diarrhea
9. Nasal catarrh
10. Vertigo

Punctiform opacities developed in the lungs of half of the welders. Measurement of zinc concentrations in the various holds of the ship during welding showed the following values (random observations):

Zinc oxide	145,700; 69,700; and 14,600 $\mu g/m^3$
Zinc dust	245,100 and 81,600 $\mu g/m^3$

The degree of zinc concentration in the air appears to be a factor in determining the toxicity of zinc oxide. Two healthy men exposed to 600,000 $\mu g/m^3$ of zinc oxide in the air developed moderate symptoms of zinc fever. One man, exposed for 10.5 minutes, inhaled 48,000 μg of zinc and retained 24,000, while the other was exposed for 12 minutes, inhaled 74,000 μg of zinc, and retained 37,000. However, Batchelor *et al*.[8] studied the case histories of 24 industrial workers engaged in zinc production. Although these men had been exposed during working hours to zinc oxide fumes at concentrations ranging from 3,000 to 15,000 $\mu g/m^3$ for periods ranging from 2 to 35 years, no acute or chronic effects had developed and the mean zinc content of the blood was only slightly above the normal level.

Zinc chloride is usually nontoxic in open atmospheres, but may be toxic when inhaled in confined spaces. Hunter[24] reports one instance in which 10 deaths and 25 non-fatal injuries occurred among 70 persons exposed to high concentrations of zinc chloride fumes. The fumes were emitted from a bank of 79 smoke generators 80 yards from the entrance to a tunnel in which the men were working. The high concentration of the fumes in an enclosed space, together with the elevated heat of the particles, probably produced the highly toxic effects. Deaths occurred either immediately after the accident or within a few hours, apparently as the result of shock together with massive pulmonary edema.

According to Gafafer,[19] inhalation of zinc chloride may produce severe pneumonitis. For instance, when used in smoke-screening compounds, zinc chloride has been known to produce insidious chemical pneumonitis among military personnel. It is also reported to be extremely irritating to eyes, nose, and throat, possibly producing perforation of the nasal septum.

Exposure to mists or fumes of zinc salts may irritate the respiratory or gastrointestinal tracts. It has been suggested that zinc oxide may block the sebaceous gland ducts and produce a papulopustular eczema in men packing zinc oxide in barrels.[56] Uotila _et al_.[57] consider zinc stearate to be a possible causative agent in pneumonoconiosis.

In a statistical study,[11] measured concentrations of trace elements in 28 cities during the period 1957-1961 (with 26 biweekly samples per year) were plotted against the corresponding rates of mortality from hypertension and arteriosclerotic heart disease. Zinc was found to be the only pollutant, other than cadmium, with a significant coefficient of association. The value of the correlation coefficient for zinc was found to be 0.556.

Particle size, an important factor in the retention of particulate matter by the respiratory system, may be related to the differing toxic effects of zinc oxide and zinc chloride. Figure 1 indicates the size (in microns) of zinc particles found in the atmosphere; Figure 2 presents the retention of particles by the respiratory system according to the size of the particulate matter.[21]

2.1.2 Ingestion

Normal dietary intake of zinc has been estimated at 10,000 to 15,000 μg a day. Zinc poisoning may occur on ingestion of excessive amounts with food and drink, resulting in an acute transitory illness within minutes. The symptoms include malaise, dizziness, tightness of throat, vomiting,

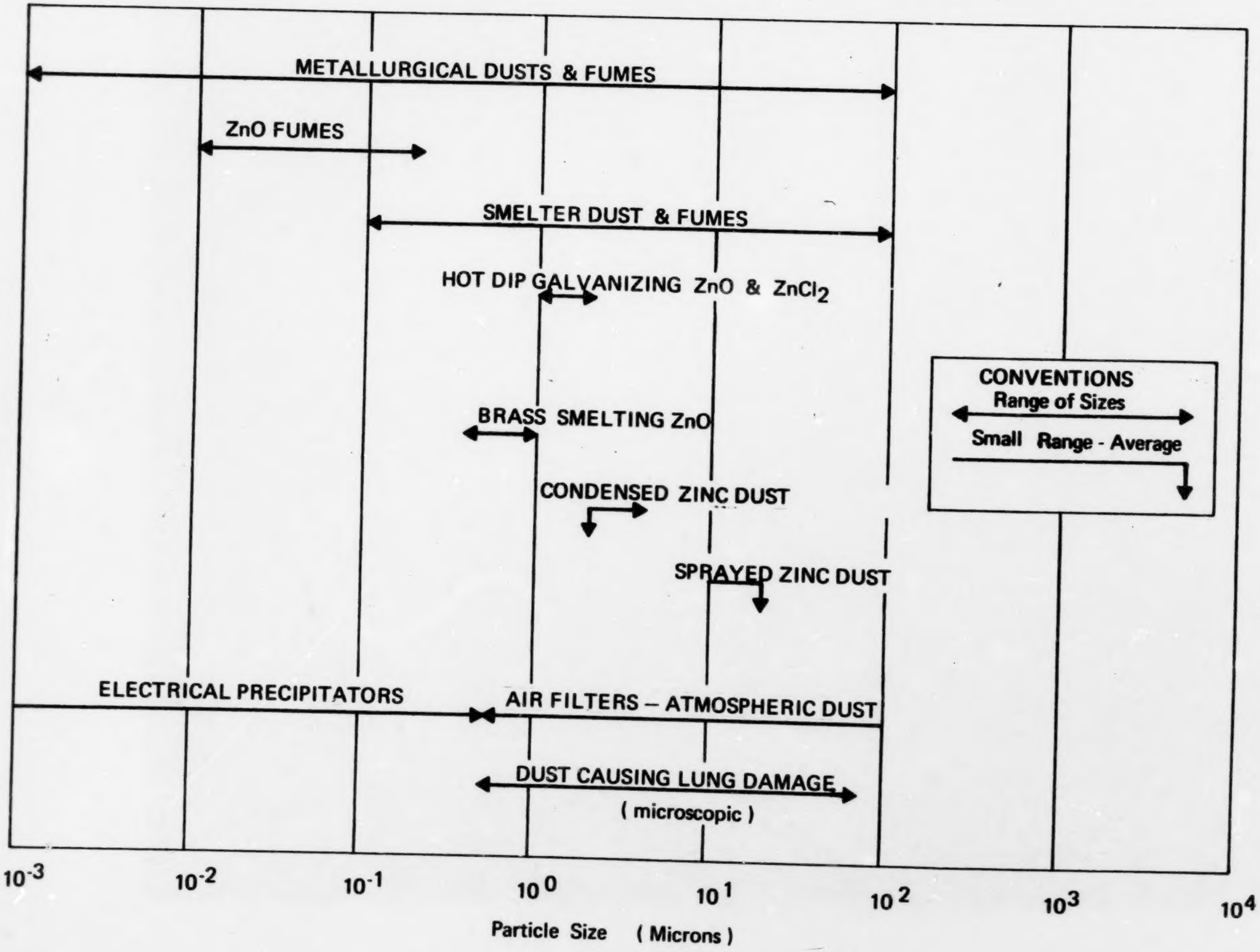

FIGURE 1. Size Ranges of Zinc in the Atmosphere[28]

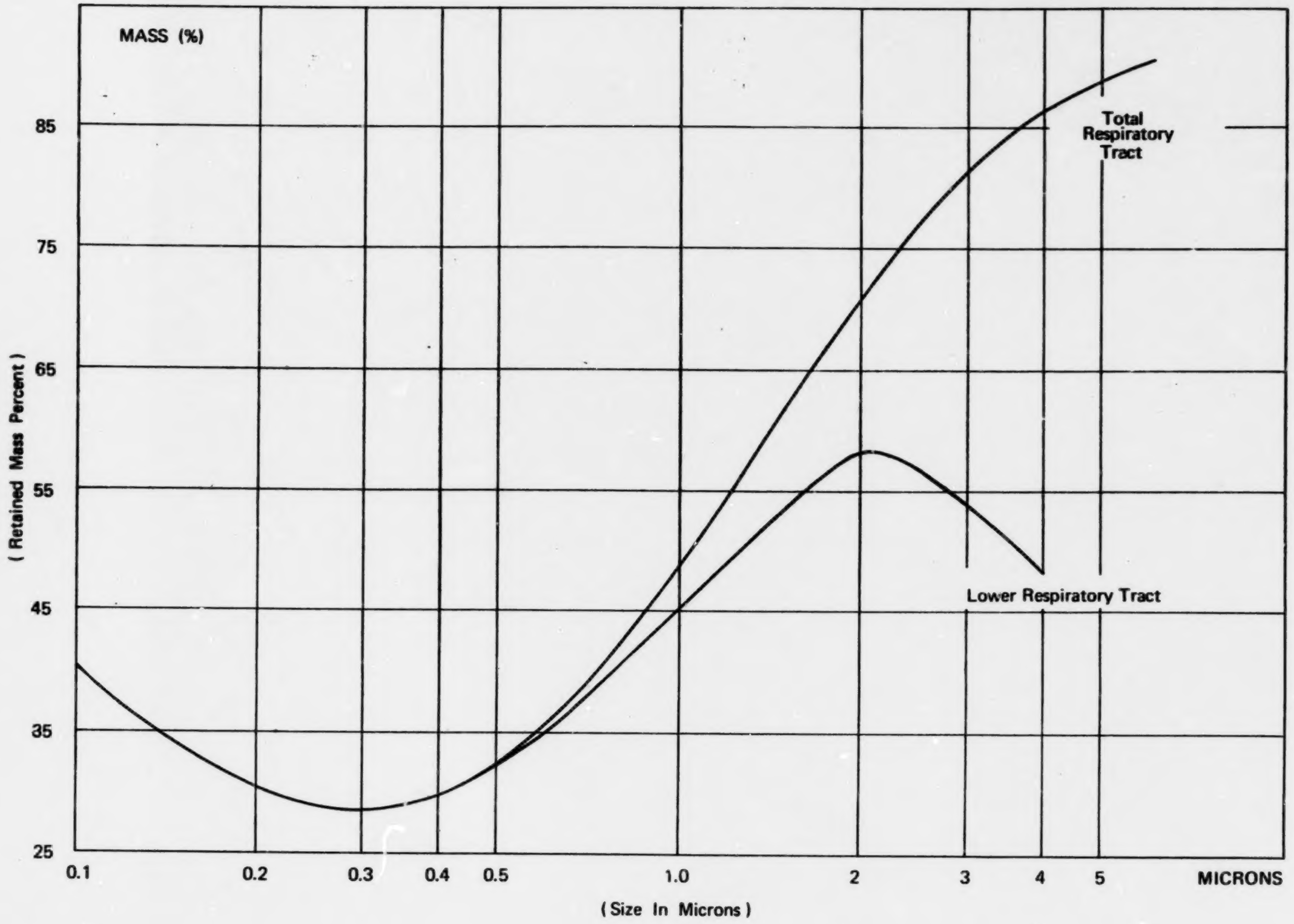

FIGURE 2

Lung Retention of Inhaled Particles as a Function of Their Size for the Relevant Region (Size of Zinc Particles)[6] colic, and diarrhea. Treatment is symptomatic. The excess zinc intake can usually be traced to the preparation of acid foods in galvanized containers.[36,37]

In a study by Brown[10] of 400 persons exposed to food contaminated by zinc salts, zinc concentrations of up to 1,200 ppm (dry weight), or 0.12 percent by weight, were found in some of the 300 or more who developed symptoms of poisoning.

In another case of mass poisoning, 44 out of 51 persons who drank punch stored in a galvanized container became ill. Quantitative analysis showed 3,675 ppm of zinc in the punch (or 3.7 percent) by weight.[10]

According to Schroeder _et al_.,[46] acute zinc intoxication attributed to ingestion of acid foods prepared in galvanized containers may in fact be caused by the toxic effects of cadmium as a result of the 1.0 percent or more present in galvanized materials.

Zinc ion ordinarily is not absorbed in sufficient quantities to cause acute systemic effects.[36]

2.1.3 Skin Contact

Development of dermatitis due to exposure to zinc salts—such as zinc chromate, zinc cyanide, and zinc sulfate—has also been reported.[19] However, according to Freeman[18], it is rare.

Zinc chloride is caustic and may result in ulceration of the fingers, hands, or forearms of persons who use it as a flux in soldering or in other occupations. However, zinc is not unique in this respect, since this type of effect may be caused by any strong acid or alkali.

2.2 Effects on Animals

2.2.1 Commercial and Domestic Animals

Stokinger[50] has reported that cattle and horses were poisoned by inhaling air contaminated by zinc and lead within 5 miles of zinc and lead smelters. The main effects included emaciation and swelling of limb joints, causing severe lameness and necessitating slaughter. These effects were reproduced in animals that were fed samples of dust collected in the area containing 45 percent lead, 5 percent zinc, and traces of arsenic and fluoride. The additive effects of zinc to lead, if any, were not stated.

2.2.2 Experimental Animals

2.2.2.1 Inhalation

Exposure of 132 rats (weighing 250 g each) to zinc oxide fumes at 400 to 600 $\mu g/m^3$ for 10 to 120 minutes (particle size: 0.7-1.6 μ) resulted in 16 deaths. Other rats showed a marked fall in body temperature, which was increased when zinc oxide was irradiated by ultraviolet light for 50 seconds. In sacrificed animals, 1,100-5,500 μg of zinc for each gram of lung tissue was found.[9]

Dogs and cats were found to tolerate exposures of 175,000-1,000,000 $\mu g/m^3$ of zinc oxide for periods ranging from

3 to 53 weeks. Nevertheless, glycosuria occurred in the dogs, while fibrous degeneration of the pancreas was noted in some of the cats. Exposure to 500-34,400 μg/m³ of zinc oxide for from one month to one year produced no injury to rats.[15]

Cats exposed to zinc ammonium sulfate (particle size: <2.5 μ) at concentrations ranging from 40,000 to 50,000 μg/m³ for 3 minutes showed increased resistance in total pulmonary air flow, and decreased pulmonary compliance.[27] Guinea pigs exposed to 1,000 μg/m³ for 60 minutes (particle size: 0.29-0.74 μ) showed only increased resistance in total pulmonary flow.[5]

In another study,[4] 42 guinea pigs weighing 200-300 g were exposed to aqueous aerosols of zinc ammonium sulfate at 900 (150-1,800) μg/m³ for one hour (particle size: 0.29 μ). Another set of 10 guinea pigs of the same weight was exposed to 1,400 μg/m³ for one hour (particle size: 0.74 μ). Still another group of 21 comparable guinea pigs was exposed to 2,000 (1,500-2,430) μg/m³ for one hour (particle size: 0.5 μ). Finally, 11 guinea pigs were exposed to 2,400 (1,100-3,600) μg/m³ for one hour (particle size: 1.4 μ). The results of these tests indicated increased air flow resistance in all cases except the last (particle size: 1.4 μ). It was also found that zinc ammonium sulfate was twice as potent as zinc sulfate, and approximately three to four times more potent than ammonium sulfate.

2.2.2.2 Ingestion

Sadasivan[40,41,42] found that rats fed diets containing 0.5 and 1 percent of zinc oxide showed reductions in the weight and fat content of livers and femurs. As a result, they developed subnormal calcium-phenyl ratios, increased excretion of urinary and fecal nitrogen, decreased urinary excretion of phenyl and sulfur (but increased fecal excretion), increased urinary uric acid and creatinine, and increased liver and kidney alkaline phosphatase activities.

Heller _et al._[22] reported that young rats fed a diet containing 0.25 percent zinc in the form of zinc dust, zinc chloride, zinc carbonate, and zinc sulfate showed no reduction in growth or other apparent effects. Three generations were maintained and fed the same diet without effects on vigor, growth, and reproduction or obvious changes of the internal organs.

Waltner _et al._[62] reported that feeding zinc carbonate to rats induced anemia and osteoporosis.

Zinc acetate fed to rats for 4 months at doses of 10,000 to 15,000 μg per day did not cause intoxication, according to Salant.[44] He also reported that zinc malate fed to cats for 11 days to 2 months produced no toxic effects.

Sutton _et al._[52] found that rats could tolerate concentrations of 0.1 percent zinc in the diet, but that more than 0.5 percent reduced their capacity to reproduce, while 1 percent inhibited growth and caused severe anemia and death.

These authors noted that the toxic level for zinc ions—as measured by adverse effects on growth and hemoglobin levels and reproduction—ranged between 0.5 percent and 1.0 percent of the dietary intake for young rats. Diets which incorporated these levels of zinc in the form of zinc carbonate for 39 weeks produced a drop in hemoglobin levels to 10,200 μg/100 ml for the 0.5 percent level and 6,100 μg/100, for the 1.0 percent level, as well as hypochromic or microcytic anemia.[52]

Dietary levels of 500,000 to 700,000 μg zinc administered to rats as zinc carbonate resulted in marked reduction in liver catalase and cytochrome oxidase activities. These effects were reversed by simultaneous administration of copper sulfate. However, copper sulfate did not reverse the produced growth inhibition.[16,60,61,64]

Studies of the relationship between zinc and calcium have indicated that zinc decreases the normal deposition of calcium and phosphorus in the bones of young rats. This effect can be reversed by supplementary intake of the decreased elements. Dietary intake of zinc can also cause an increase in fecal and urinary elimination of calcium and phosphorus and thus a reduction in retention of these elements.[23,34,48]

After administration of copper salts, normal rats and rats intoxicated with zinc were found to have 27,000 μg/kg (dry weight) and 10,000 μg/kg respectively of copper in the heart.

Glycosuria and albuminuria may develop in rabbits as the result of prolonged and excessive zinc feeding or following intravenous injection of zinc salts.[43]

Duncan et al.,[16] however, found that rats exposed to diets with 0.4 percent zinc for 42 days became anemic after 4 days. The iron content of the liver dropped after 7 days, and the copper content of the liver dropped consistently after 21 to 28 days, while the zinc content of the liver increased rapidly after only one day on the diet.[12]

Cox et al.[12] report that rats fed 0.4 percent of the diet as zinc in the form of zinc oxide were found to have reduced iron, ferritin, hemosiderin, and hemoglobin in the liver. Of the iron lost, 77 percent was from ferritin and 20 percent from hemosiderin.

Data on zinc toxicity in experimental animals are given in Table 1.

2.2.2.3 Injection

One group of 12 guinea pigs was injected with a single dose of zinc silicate, and a comparable group with a single dose of zinc beryllium silicate at concentrations of 0.75 ml of 1 percent salt suspension.[42] Both groups developed lesions consisting of histiocytes, lymphocytes, plasma cells, and fibroblasts. In the group injected with zinc beryllium silicate, these lesions were severe, reaching their maximum level 2 weeks after the injection and progressing for 3 or 4

TABLE 1

SELECTED DATA ON ACUTE ZINC TOXICITY IN EXPERIMENTAL ANIMALS[59]

Zinc Compound	Animal[a]	Route of Admin.[b]		Dosage µg/kg
Zinc acetate	Rabbit	or	MLD	976,000-1,966,000
Zinc chloride	Rat	iv	LD	60,000-90,000[c]
Zinc diethyldithiocarbamate	Rabbit	or	LD_{50}	600,000
Zinc ethylene-bis-dithiocarbamate	Rat	or	LD_{50}	>5,200,000
Zinc phosphide	Rat[d]	or	LD_{50}	40,500±2,900
	Rat	or	LD_{50}	46,700
Zinc sulfate,[e] $ZnSO_4 \cdot 7H_2O$	Frog	sc	LD	149,000
	Rat	or	LD	2,200,000
	Rat	sc	LD	330,000-440,000
	Rat	iv	LD	49,300-61,000
	Rabbit	or	LD	1,914,000-2,200,000
	Rabbit	sc	LD	>220,000-440,000
	Rabbit	iv	LD	44,000
	Dog	sc	LD	78,000
	Dog	iv	LD	66,000-110,000
Ziram	Mouse♀	ip	LD_{50}	73,000±1,000
	Rat	or	LD_{50}	1,400,000±99,000
	Rat♂	ip	LD_{50}	23,000±2,000
	Rat♀	ip	LD_{50}	33,000±5,000
	Guinea pig	or	LD_{50}	100,000-150,000
	Guinea pig	ip	LD_{50}	20,000-30,000
	Rabbit	or	LD_{50}	100,000-1,020,000
	Rabbit	or	LD_{50}	400,000
	Rabbit	ip	LD_{50}	5,000-50,000

[a] ♀: female; ♂: male.

[b] ip: intraperitoneal; iv: intravenous; or: oral; sc: subcutaneous.

[c] 1% solution in H_2O.

[d] Norway.

[e] The most common form of zinc sulfate.

months. However, at 15 months only residual damage was observed. During the second week, the respiratory epithelia of bronchi and bronchioles were largely destroyed. In the group injected with zinc silicate, less severe lesions developed that reached their maximum level in 8 weeks. At 2 weeks the following symptoms were observed: (1) proliferation of alveolar cells, (2) infiltration of alveolar walls by histiocytes, (3) fusing of alveolar walls, and (4) obliteration of functional alveoli. At 4 weeks, proliferation increased, and alveoli partitions greatly thickened. At 8 weeks, histiocytes became predominant, and some giant cells appeared. Lesions were found to persist 3 months after the injection.[42]

Subcutaneous injection of 0.5-1 g of finely powdered zinc in rabbits resulted in intracapillary glomerulonephritis.[13]

2.3 Effects on Plants

Although zinc is essential to living tissues of plants, increasing the rate of photosynthesis in some instances, excessive quantities of the metal may be expected to cause adverse effects.[7] For example, a Montana smelter discharged daily into the atmosphere 3 tons of zinc, 2 tons of copper, and 2 tons of lead, in addition to 2,500 tons of sulfur oxides. The resulting acidic condition of the atmosphere, acting together with the high concentrations of zinc and other metals, has left the surrounding land barren and eroded. Studies have been made of the adverse effects on plants resulting from excessive concentrations of a number of trace metals, such as copper, cobalt, chromium, and nickel, but no study has been found concerning the effects of zinc.[17]

2.4 Effect on Materials

No information is available on the adverse effects on materials of zinc in the environmental air. Actually, zinc is used more than any other metal to protect materials from corrosion by atmospheric pollutants.[20]

2.5 Environmental Air Standards

Handbooks on the dangerous properties of industrial materials list approximately 60 zinc compounds. Threshold limit values (TLV) have been established only for zinc oxide fumes. The 1967 American Conference of Government Industrial Hygienists adopted the value of 5,000 $\mu g/m^3$ for zinc oxide fumes (averaged over the 8-hour workday) for those occupationally exposed. The value adopted is a revision of the previously accepted value of 18,000 $\mu g/m^3$. This original TLV was based on a study by a group of researchers who found no acute or chronic illness in their examinations of 24 workers exposed during working hours to zinc oxide fumes at levels of about 3,000-15,000 $\mu g/m^3$ for periods of from 2 to 35 years.

A maximum allowable concentration for zinc oxide fumes of 5,000 $\mu g/m^3$ per 8-hour workday was established by 1965 in both the Federal Republic of Germany[28] and in the U.S.S.R.[55]

A tentative threshold limit value of 1,000 μg/m^3 was set for those occupationally exposed to zinc chloride by the American Conference of Governmental Industrial Hygienists in 1966.

3. SOURCES

The primary sources of emissions of zinc compounds into the atmosphere are zinc, lead, and copper smelting operations, secondary processing to recover scrap zinc, and possibly the incineration of zinc-bearing materials. Zinc oxide fumes are the zinc compounds most commonly emitted from these sources.

3.1 Natural Occurrence

Zinc, widely distributed in the earth's crust, occurs in small quantities in almost all igneous rocks. Sphalerite, or zinc blende (ZnS)—the major zinc mineral—is commonly associated with lead and iron sulfides. Most sphalerite has cadmium associated as a coating or solid solution in quantities ranging from traces to 2 percent.

Table 2 presents the zinc composition and content of the economically important zinc minerals.

TABLE 2

ZINC CONTENT IN COMMERCIALLY IMPORTANT ZINC MINERALS[30]

Zinc Minerals	Composition	Zinc %
Sphalerite (zinc blende)	ZnS	67.0
Smithsonite (calamine)	$ZnCO_3$	52.0
Hemimorphite	$(ZnOH)_2SiO_3$	54.2
Zincite	ZnO	80.3
Willemite	Zn_2SiO_4	58.5
Franklinite	$(Fe,Zn,Mn)O$: $(Fe,Mn)_2O_3$	15-20

Table 16 in the Appendix contains data on the physical and chemical properties of zinc and its compounds.

3.2 Production Sources

3.2.1 Mining

Mining methods vary with the type of ore body; however, underground mining accounts for most of the production, although some open-pit mining is done. Mining processes include size reduction, separation, and production of zinc concentrates. No information was found on emissions or concentrations of zinc in the atmosphere in or around zinc mining operations. While it is most probable that zinc dusts and/or fumes are present, no instances were noted in the literature of any illnesses connected with mining.

Table 3 lists the leading zinc-producing mines in the United States. Table 4 presents data on the production of zinc ore by state for the period 1963-1967 inclusive.

3.2.2 Smelting and Refining

3.2.2.1 Primary Zinc Production

The reduction of zinc ores and concentrates to zinc is accomplished in primary reduction plants by the electrolytic deposition of zinc from an ore solution, or by distillation in retorts or furnaces. In either procedure the zinc concentrate is roasted to eliminate most of the sulfur and to produce zinc oxide.

The extraction of zinc from roasted concentrates involves the heating of a mixture of roast and coke to about 1100°C. Reduction of zinc from the oxide to the metal and distillation

TABLE 3

LEADING ZINC-PRODUCING MINES IN THE UNITED STATES IN 1967 IN ORDER OF OUTPUT[32]

Rank	Mine	State	County	Operator	Source of Zinc (Ores)
1	Balmat	N.Y.	St.Lawrence	St. Joseph Lead Co.	Pb-Zn
2	Friedensville	Pa.	Lehigh	The N.J. Zinc Co.	Zn
3	Sterling Hill	N.J.	Sussex	The N.J. Zinc Co.	Zn
4	Young	Tenn.	Jefferson	American Zinc Co.	Zn
5	Eagle	Colo.	Eagle	The N.J. Zinc Co.	Zn, Cu
6	Bunker Hill	Idaho	Shoshone	The Bunker Hill Co.	Pb-Zn
7	Zinc Mine Works	Tenn.	Jefferson	U.S. Steel Corp.	Zn
8	Austinville & Ivanhoe	Va.	Wythe	The N.J. Zinc Co.	Pb-Zn
9	Star-Morning	Idaho	Shoshone	Hecla Mining Co.	Pb-Zn
10	Edwards	N.Y.	St.Lawrence	St. Joseph Lead Co.	Zn
11	Idarado	Colo.	Ouray and San Miguel	Idarado Mining Co.	Cu-Pb-Zn
12	New Market	Tenn.	Jefferson	New Market Zinc Co.	Zn
13	Jefferson City	Tenn.	Jefferson	The N.J. Zinc Co.	Zn
14	Calhoun	Wash.	Stevens	American Zinc Co.	Zn
15	U.S. and Lark	Utah	Salt Lake	U.S. Smelting, Refining, and Mining Co.	Pb-Zn
16	Flat Gap	Tenn.	Hancock	The N.J. Zinc Co.	Zn
17	Mascot No.2	Tenn.	Knox	American Zinc Co.	Zn
18	Shullsburg	Wis.	Lafayette	Eagle-Picher Ind. Inc.	Zn
19	Iron King	Ariz.	Yavapai	Shattuck Denn Mining Corp.	Pb-Zn
20	Copperhill	Tenn.	Polk	Tenn. Copper Co.	Cu-Zn
21	Deardorff Group	Ill.	Hardin and Pope	Ozark-Mahoning Mining Co.	F*-Pb-Zn
22	Burgin	Utah	Utah	Kennecott Copper Corp.	Pb-Zn
23	Hanover	N.Mex.	Grant	The N.J. Zinc Co.	Zn
24	Oswaldo	N.Mex.	Grant	The N.J. Zinc Co.	Zn
25	Page	Idaho	Shoshone	Am. Smelting and Ref. Co.	Pb-Zn

*Fluorspar.

TABLE 4

MINE PRODUCTION OF RECOVERABLE ZINC IN THE UNITED STATES, BY STATES, LISTED BY ORDER OF THEIR 1967 PRODUCTION[32]

(Short Tons)

State	1963	1964	1965	1966	1967
Tennessee	95,847	115,943	122,387	103,117	113,065
New York	53,495	60,754	69,880	73,454	70,555
Idaho	63,267	59,298	58,034	60,997	56,528
Colorado	48,109	53,682	53,870	54,822	52,442
Pennsylvania	27,389	30,754	27,635	28,080	35,067
Utah	36,179	31,428	27,747	37,323	34,251
Wisconsin	15,114	26,278	26,993	24,775	28,953
New Jersey	32,738	32,926	38,297	25,237	26,041
Washington	22,270	24,296	22,230	24,772	21,540
New Mexico	12,938	29,833	36,460	29,296	21,380
Illinois	20,337	13,800	18,314	15,192	20,416
Virginia	23,988	21,004	20,491	17,666	18,846
Arizona	25,419	24,690	21,757	15,985	14,330
Oklahoma	13,245	12,159	12,715	11,237	10,670
Missouri	321	1,501	4,312	3,968	7,430
Kentucky	1,461	2,063	5,654	6,586	6,317
Kansas	3,508	4,665	6,508	4,769	4,765
Montana	32,941	29,059	33,786	29,120	3,341
Nevada	571	582	3,858	5,827	3,035
California	101	143	225	335	441
North Carolina	13				
Oregon	3	*	*		
Total	529,254	574,858	611,153	572,558	549,413

*Withheld to avoid disclosing individual company confidential data; excluded from total.

of the metal take place simultaneously. Zinc vapor passes from the heated vessel into a condenser where it is converted into liquid form and withdrawn. The reduction reaction of zinc oxide can be summarized by the reaction

$$ZnO + C \rightarrow Zn + CO$$

During the refining process, zinc fumes and dust are discharged into the atmosphere. In spite of the fact that hoods, baghouses, and Cottrell control equipment are employed, a flag of white zinc oxide fume arising from the plant is a distinctive characteristic of the zinc retort plant.[47] Stern[47] and Johnson _et al_.[25] state that the concentration of zinc fume emitted is low; however, no quantitative information was found.

The famous "Donora incident" of 1948 provides some insight into the possible emissions of zinc from a zinc-producing plant. Data from Schrenk[45] are presented in Tables 5 and 6. It is significant to note that cyclone dust collectors, Cottrell precipitators, and 125-foot-high stacks were in use at this plant. In the sinter plant, the main gas stream passed through Cottrell precipitators, and the effluent from these units was vented to the atmosphere through two stacks 110 feet high. Hot gases leaving the furnaces of the smelter plant first passed through a waste heat boiler and then were discharged to the atmosphere through a 125-foot stack. Despite these precautions, emissions of zinc compounds were substantial. Table 5 indicates emission concentrations from the roaster and the sinter plant; Table 6 provides estimates of the amount of zinc pollution per day from a zinc-producing plant.

TABLE 5

ZINC CONCENTRATIONS AT EMISSION POINTS OF A ZINC PLANT[45]
(DONORA AREA, 1948)

Emission Points	Sampling* Time Start	Sampling* Time Min	Zinc Concentration $\mu g/m^3$	Zinc Concentration % of total particulate
Roaster (Hegeler), charging platform				
Normal operation	--	13	4,800	52
Raking Period	--	5	19,400	43
Sinter Plant				
Cottrell Exhaust Stacks	11:15 am	5	62,200	17
	11:25 am	5	26,900	10
	2:25 pm	10	26,300	9
	12:01 pm	5	64,000	8
	3:15 pm	5	45,700	8

*Sampling information:
Collection instrument: electrostatic precipitator.
Sampling rate: 2 ft^3/min.
Temperature range (in sampled stacks): 135° to $1{,}000^{\circ}$ F.
Method of determination: colorimetric: dithizone using the Beckman DU spectrophotometer.

TABLE 6

ESTIMATED ATMOSPHERIC POLLUTION[45]
(LOADS OF ZINC FROM A ZINC PLANT)

	Sinter Plant (2 Stacks, 5 Cottrells)	Spelter Plant (9 boiler-stacks)
Total air flow from stack (ft^{3}x10^6)/day	86.4	600
Estimated atmospheric pollution load, lb of ZnO/day	250.	24,400
ZnO as % of total particulate	25%	91.6%

Data on the production and consumption of zinc in the United States for the years 1963-67 inclusive are given in Tables 17 and 18 in the Appendix. The major producers of slab zinc are listed in Table 19, and the primary and secondary slab zinc plants and their capacity in Tables 20 and 21 of the Appendix.

The outlook for future demand in the United States is one of continued growth with little change in the pattern of present use.[32] Figure 3 indicates the growth trends for U.S. production and consumptio~~n of zinc; the con~~tinuous growth record may be significant in relation to air pollution by zinc materials.

3.2.2.2 Primary Production of Other Metals

Zinc, or zinc dusts and fumes, are produced as a by-product in the refining of other metals, the most significant of which are copper, lead, and steel. Commercial quantities of zinc are produced in the refining of copper and lead; small nonrecoverable quantities are produced in the production of steel. In 1967, 33 percent of the zinc produced was obtained from lead-zinc ores; 2 percent from lead ores; 6 percent from copper-lead, copper-zinc, and copper-lead-zinc ores; and 6 percent from all other combinations of metal ores.[32] The balance (53 percent) of zinc produced in 1963 was obtained from zinc ores. Therefore, emissions of zinc from plants producing copper, lead, and steel can be a source of air pollution if not controlled.

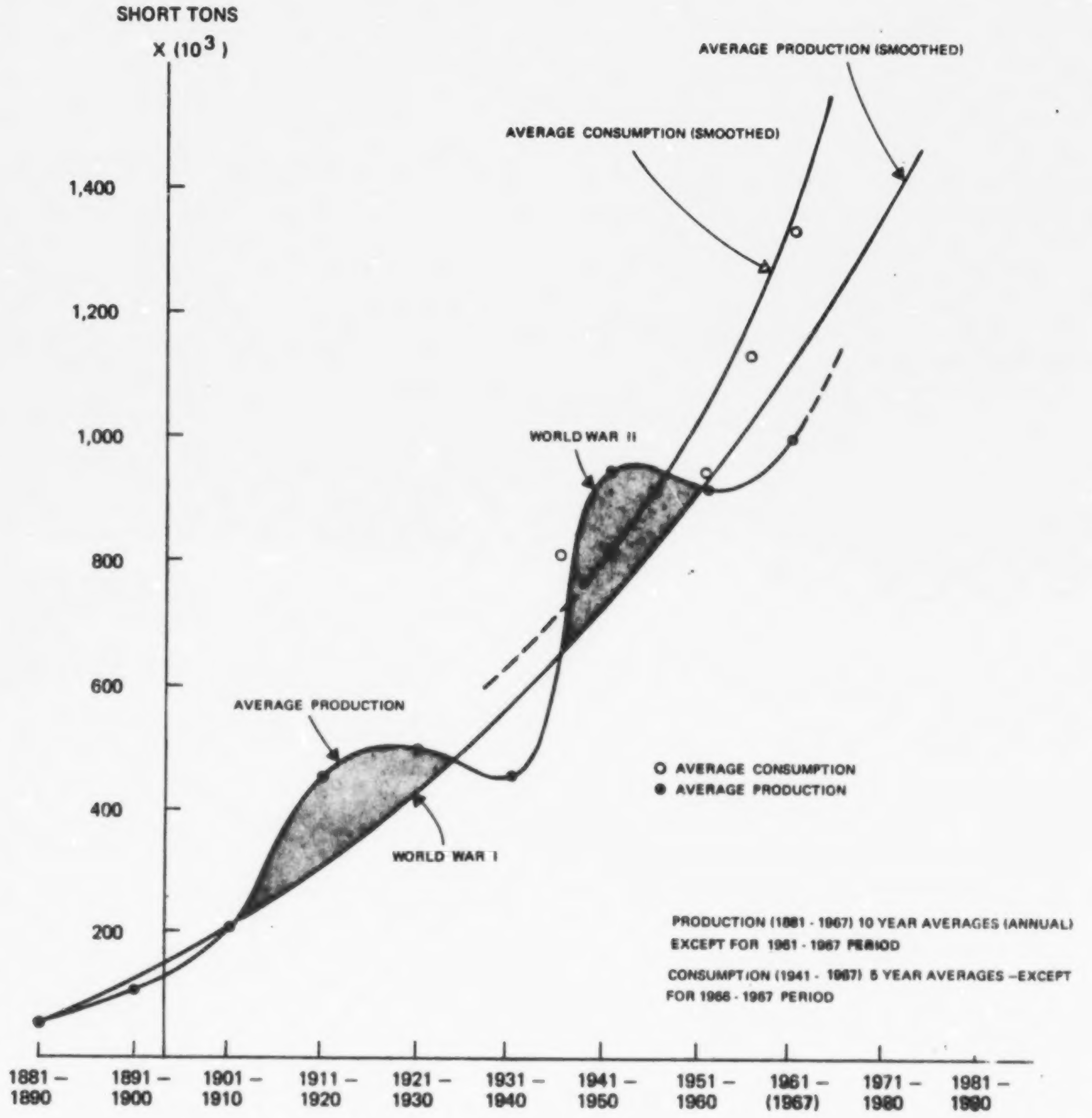

FIGURE 3

Trend Curves for Domestic Primary Zinc Production and Slab Zinc Consumption[32]

In the manufacture of steel from pig iron and scrap steel, impurities are removed by oxidation. Open-hearth furnaces, which accounted for over 85 percent of the steel produced in the United States in 1960, were found to emit a particulate discharge containing a zinc concentration of 10 to 15 percent; the zinc content stems from the use of scrap material containing galvanized steel. Zinc oxide comprised 39 percent of the discharge from electric-arc furnaces, which produced 10 percent of the total steel capacity of 1960. Since typical discharges can average as much as 137 pounds of dust and fume per hour from a 50-ton open-hearth furnace, the quantity of zinc emitted can be considerable. Even when precipitators are used that are 98.98 percent effective, a 63-ton open-hearth furnace emits 0.406 pounds of dust per hour, which equals 0.04-0.06 pounds of zinc per hour.[14]

A steel strike provided the opportunity to study the extent to which the iron, steel, and zinc industries are contributing to zinc air pollution.[53] The strike which lasted for 2 weeks, affected the refinery industry in a number of communities. Measurements of atmospheric concentrations of air pollutants were made during the strike period and again after the strike was settled. The results are summarized in Table 7. It was found that of the many pollutants sampled, only lead, zinc, and the sulfates showed significant differences in concentrations at the two sampling

TABLE 7

ZINC CONCENTRATIONS DURING STRIKE AND POST-STRIKE PERIODS IN THE STEEL INDUSTRY IN FOUR COMMUNITIES (U.S.A., 1956) AND CORRESPONDING PROBABILITY LEVELS[53]

Community	Average Concentrations ($\mu g/m^3$)				
	Post-Strike	Strike	Difference	No. of Samples	Probability[a]
Birmingham	700	200	500	9	0.028
Donora[b]	11,800	100	11,700	15	0.001
East Chicago	1,600	300	1,300	9	0.002
Allegheny County	1,100	100	1,100	8	0.009

[a] Probability of obtaining the observed differences by chance alone, limit of statistical significance: P=0.05.

[b] The only community with a zinc plant (closed during the strike).

times. Concentrations of iron and zinc during the strike period were only a fraction of those observed after operations were resumed. In Donora, the only community with a zinc plant, the concentrations during and after the strike differ by two orders of magnitude.

3.2.2.3 Secondary Zinc Refining

Scrap zinc may be converted into usable metal by the use of refining methods similar to those for primary zinc, or by melting the scraps in sweat furnaces. In the sweating process, separation of the metals occurs as a result of their differing melting temperatures. Air pollutants emitted from a zinc-sweating plant primarily consist of zinc fumes, which are negligible at low furnace temperatures, but become significant at high temperatures (above 900°F).[14] Measurements made at a zinc die-cast-sweating operation (using die-cast products such as auto grilles, license plate frames, and zinc skims and drosses) are shown in Table 8.

TABLE 8

DUST AND FUME EMISSIONS FROM A ZINC-SWEATING FURNACE CONTROLLED BY A BAGHOUSE[14]

Type of furnace	Reverbatory
Process weight, lb/hr	2,800
Material sweated	Zinc casting
Average gas temperature	180°F
Concentration ($\mu g/m^3$)	
Baghouse inlet	700
Baghouse outlet	250
Dust and fume emission (lb/hr)	
Baghouse inlet	13.5
Baghouse outlet	0.5

3.2.2.4 Secondary Brass and Bronze-Melting Processes

The remelting of high-purity copper and bronze produces only small amounts of volatilized metals. With good melting practices, total emissions should not exceed 0.5 percent of the process weight. However, brasses containing 15 to 40 percent zinc are poured at about 2,200°F, and vaporization of zinc is therefore inevitable. Emissions of zinc fumes may vary from less than 0.5 percent to 6 percent or more of the total metal charge and from 2 to 15 percent of the total zinc content of the charge, depending on the composition of the alloy, the type of furnace, and the procedures used.[14]

A recent study[65] of a secondary metal smelter in Baltimore, Md. (K. Hettlemans & Sons, subsidiary of Minerals and Chemicals Philipp Corp.), revealed considerable emission of zinc oxide dust. The input to this operation is raw scrap of used brass or bronze (radiators, castings, plumbing fixtures, valve bronzes, naval alloys, manganese-bronze ship propellers, etc.). The output consists of (1) alloys for plumbing and (2) zinc oxide dust (containing chlorine and lead). The installation of proper air pollution control devices (described under methods of abatement) appears to have solved the emission problem.

3.3 Product Sources

Zinc and its compounds are emitted into the atmosphere as a result of many different uses of these materials. The most significant, from an air pollution view, seem to be the use of zinc in galvanizing of iron or steel, and its use in producing alloys of brass. Other possible sources of pollution include incineration of zinc-bearing products.

3.3.1 Zinc Galvanizing

This process involves coating iron or steel with a thin layer of zinc by immersion in molten zinc at temperatures of 840° to 860°F.

The subprocesses involved are:

1. Degreasing
2. Rinsing
3. Pickling in acid bath
4. Rinsing
5. Prefixing in zinc ammonium chloride
6. Immersing the article in molten zinc through a molten flux cover
7. Finishing

The emissions from galvanizing kettles have been shown to contain zinc, zinc oxide, and zinc chloride,[14] among other pollutants.

Results of the chemical analysis of the fumes collected from zinc-galvanizing kettles by a baghouse and by an electric precipitator are shown in Table 9.

TABLE 9

ANALYSIS OF FUMES FROM ZINC GALVANIZING KETTLES[14]

(% wt)	Baghouse (Job-shop kettle)	Precipitator (Chain-link galv.)
Zinc	15.8	6.5
ZnO	3.6	15.2
$ZnCl_2$	4.9	
Total	24.3	21.7

Fumes discharged from continuous galvanizing of chain-link fence were shown to have a different composition: 15.2 percent of zinc chloride and 6.5 percent of zinc oxide.

3.3.2 Brass Production

Brass is made by adding zinc to molten copper. The properties of brass depend upon the zinc content, which ranges from 5 to 40 percent. Zinc fumes, a natural product of this process, if uncontrolled will escape into the atmosphere. Data on the emissions from different types of furnaces producing brass are presented in Table 10.

TABLE 10

EMISSIONS FROM VARIOUS TYPES OF BRASS FURNACES[14]

Type of Furnace	Zinc in Alloy Produced (%)	Pouring Temperature (°F)	Process Weight (lb/hr)	Fume Emission (lb/hr)
Rotary	5	No data	1,104	22.5
Rotary	14.7	No data	3,607	25.
Rotary	5	No data	1,165	2.73
Electric (induction)	38	No data	1,530	3.47
Electric (induction)	28	No data	1,600	0.77
Electric (induction)	28	No data	1,500	0.54
Cyl. reverberatory	4	No data	273	2.42
Crucible	2	2,100	1,250	10.9
Crucible	35	2,100	470	8.67
Crucible	37	1,900-2,100	108	0.05
Crucible	12	1,800	500	0.882

Particulate emissions from furnace stack gases in copper-base alloy foundries may contain as much as 98 percent of zinc oxide and/or lead. A series of tests in Los Angeles County showed an average of 59 percent of zinc oxide in the fumes from the manufacture of representative red and yellow brass and a dust-and fume-loading at stack conditions of from 0.022 to 0.771 grain per cubic feet.

3.3.3 Incineration

Little is known about zinc pollution of the atmosphere resulting from incineration of waste material. It is probable that small quantities of zinc are discharged into the air from incineration of zinc-bearing materials, such as dry-cell batteries, or reduction of old auto bodies.

3.4 Environmental Air Concentrations

Air quality data obtained from the National Air Sampling Network are shown in Table 22 in the Appendix. The national 24-hour average concentration of zinc in the atmosphere was 0.67 μg/m^3 during the period 1960-64; the maximum value recorded during that period was 58.00 μg/m^3 in 1963 at East St. Louis, Ill.

Measurements made in 1954 in seven major European cities[49] showed the following mean annual values for atmospheric zinc concentrations:

Oslo	1.360	μg/m^3
Liverpool	0.279	"
Dublin	0.240	"
Helsinki	0.196	"
Belfast	0.160	"
N. Wales	0.107	"
Copenhagen	0.000	"

The high concentration of zinc in Oslo was attributed to the large number of special industries located there.

4. ABATEMENT

4.1 Primary Zinc-Smelting Operations

Following is a description of the system of air pollution control equipment used at a major zinc-smelting operation.

Sinter machine exhaust gases are preconditioned to lower the electrical resistance of the gases. They are then processed in electrostatic rod-curtain-type precipitators, further treated in cyclone scrubbers, and then vented to the atmosphere through a 402-foot chimney. Plant dusts and fumes (other than from the sinter machine) are collected in a 275,000 CFM bag collector which discharges to a 168-foot chimney.

Sinter machines, in the agglomeration of the roaster calcines, produce large quantities of zinc fume. As zinc fume has high electrical resistance, it must be preconditioned prior to processing by the electrostatic precipitators. This conditioning is achieved by treating the fumes with large quantities of finely atomized water in conditioning chambers. Water at a pressure of 500 psi and a flow of 350 gpm is used to achieve the required atomization.

Following the preconditioning, the gases and fumes pass to rod-curtain-type electrostatic precipitators, operating with a collection efficiency of 90 percent, with an associated dust loading in the exit gases of 0.05 grains per cubic foot.

Two concrete cyclone scrubbers (25 feet in diameter by 50 feet high) further treat sintering gases before they are vented to the atmosphere. Their collection efficiency is approximately 50 percent, so that the overall removal of fume from the sintering gases is of the order of 95 percent, with a concentration in stack gases of approximately .02 grains per cubic foot STP.*

For the control of dust and fume other than from the sinter machines, a central cloth-bag collector system is used with a capacity of 275,000 cubic feet per minute. The dust-loading entering the collector is about 4 grains per cubic foot, and the collector's efficiency is 99.9 percent. The dust has approximately the same composition as sinter and is returned to the sinter circuits.

The collector is a 56-section Dracco with 4,480 bags (56 sections by 80 bags each, the bags measuring 8 inches by 10 feet). The discharge duct is 11 feet in diameter and leads to the inlet of a No. 19 SCLD Buffalo exhauster discharging at a 168-foot masonry chimney. The exhauster is operated at 225,000 cfm (total at high speed operation).

The above described system is in use in the Josephtown zinc-smelting plant. No comparative data exist for the major primary zinc-smelting operations identified elsewhere.

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*STP: Standard temperature, pressure.

The quantities of zinc dust emitted to the atmosphere by a copper-smelting plant in Manitoba before installation of a filtration system[38] are listed in Table 11. After installation of an efficient filtration system, each day more than 35 tons of dust with a zinc content of approximately 30 percent were recovered.

TABLE 11

SMELTING GAS STREAMS AND DUST BURDEN
BEFORE REVISION FOR FILTRATION OF GASES (1951)[38]

			Dust Burden		
	Flow CFM at NTP	Temperature (°F)	(tons/day)	Zinc %	Zinc (tons/day)
Dryer gas	18,000	325		3.7	0.037
Roaster gas	67,000	350	550.62	8.1	4.45
Reverb gas	100,000	1020	4818.3	18.4	8.83
Combined flow at Cottrells	204,000	440	95	12.7	12.06
Cottrell recovery			71	9.2	6.53
Cottrell loss			24	23.0	5.53
Converter gas	100,000	800	23	28.6	6.58
Cottrell recovery			6	16.7	1.00
Cottrell loss			17	32.8	5.58

4.2 Secondary Zinc Melting Operations

When hoods of the proper type are used, they prove to be very effective in all the three types of furnaces (Belgian, distillation, and muffle). The hoods are usually placed directly above the furnace or over the charge in doors of the sweat chambers (muffle furnaces). Comparative data on hood efficiency for the various types of furnaces are given in Table 12.

TABLE 12

COMPARATIVE DATA ON HOODS USED IN VARIOUS TYPES OF FURNACES[38]

Type of furnace	Ventilation (cfm)	Indraft Velocity (fpm)
Belgian retort		175
Distillation retort		
Hood above the retort	2,000	400
Hood on "speise hold"	200	250
Muffle furnaces		
Hood over charger door	3,200	700
Hood over discharger/screen	5,500	250
Hood over residue-tapping spout	8,700	900

Baghouses and precipitators are the most commonly and efficiently used control equipment in all the above-mentioned types of furnaces. Relevant data on a few control systems in use are given in Table 13.

TABLE 13

COMPARATIVE DATA ON AIR POLLUTION CONTROL EQUIPMENT USED IN TWO SECONDARY-ZINC MELTING OPERATIONS[38]

Data	Case A	Case B
Output (product)	Zinc or ZnO	ZnO
Type of furnace	Muffle	Muffle
Type of equipment used	Baghouse and cyclone	Baghouse and cyclone
Type of baghouse	6-section, pull-through type	9-section, standard
Cloth filtering area (ft^2)	5,600	16,848
Type of cloth	Glass	Orlon
Filtering velocity (fpm)	3	1.8
Efficiency, total	90%	100%
Baghouse		80%
Cyclone	5-10%	20%

4.3 Galvanizing Operations

In job shops it is necessary to use high-canopy or room-type hoods. The amount of ventilation volume necessary for use with high-canopy hoods as well as the size of the collector required increases considerably with the height of the hood. Low-canopy hoods can be used for a galvanizing kettle when head room is not required.

Due to the fact that particles range from submicron to 2 microns in size, the only efficient control devices are baghouses or high-efficiency electrostatic precipitators (used in the presence of oil mists).

Cotton bags have proved effective as collectors in most galvanizing operations. The tendency of fumes to coagulate makes it difficult to clean the bags with mechanical shakers. Because of high velocities (above 2 fpm) which also make cleaning of the bags extremely difficult and because of the large exhaust volumes required, large-sized baghouses are needed.

4.4 Zinc-Alloy Sweating Operations

The types of hooding and ventilation mentioned in a foregoing section on brass-melting operations are also used with good results in zinc-alloy sweating operations. In low-temperature operations, auxiliary hooding is usually necessary, varying with the type of sweating operation. Normally, an inlet velocity of 100 to 200 fpm is sufficient to prevent emissions to the atmosphere.

A baghouse together with an afterburner is used to collect the dust and fumes. The maximum recommended baghouse filter velocity is 3 fpm.

4.5 Secondary Brass Melting Operations

The collection of zinc oxide fumes in brass-melting operations is a problem both economically and technically. Most zinc oxide particles are of submicron size and can be handled by precipitators; however, zinc oxide particles emitted from brass furnaces are found in the 0.3-1.0 μ range (Figure 1, Page 7), where even the most efficient precipitators operate at low efficiency ratios.

As already stated, zinc oxide fumes have been found to represent, on the average, 59 percent of the stack emissions from brass furnaces. The absolute amount of dust and fume from these sources varies from 0.022 to 0.771 grains per standard cubic foot at stack conditions.

The usual controls for the various types of furnaces are slag (crushed glass) and flux (borax, soda ash, etc.) covers. However, it is necessary to control the thickness of slag covers in order to minimize emissions. In addition, if the alloy contains more than 7 percent zinc, these covers do not sufficiently suppress emissions. On the other hand, flux covers usually destroy the furnace walls.

Of all the available types of air pollution control equipment, only baghouses have proved sufficiently economical and efficient for secondary-brass-smelting operations.

Electric precipitators have not proven entirely satisfactory for the control of zinc oxide fumes because of (1) the high resistivity of the fumes, (2) the unavailability of small high-voltage precipitators suitable for the average size of the operations in question, and (3) the fact that at the particle-size range below 0.5 micron the efficiency of electrostatic precipitators drops considerably.

Scrubbers (dynamic) or washers (mechanical) have proved (1) to be ineffective in the submicron range, (2) to consume much power, (3) to be subject to mechanical wear, and (4) usually to necessitate separation of the fumes and other particulate matter.

Collectors (centrifugal) are also inefficient in the submicron range. In one instance, a tested cyclone (wet) had to be replaced by baghouses in the end.

4.6 Open-Hearth and Electric-Arc Furnaces, Steel Operations

Metal fumes and oxides from open-hearth and electric-arc furnaces for making steel alloys amount to 99 and 75 percent (by weight) of the total emissions respectively. The corresponding percentages of zinc are 15 and 37. In spite of this, no air pollution control devices have been used or recommended. The alleged reason is that the absolute amounts of particulate emission have been found to be 0.00278 grain per standard cubic foot or 0.14 pound per hour (for a furnace rated at 1,000 pounds capacity). This has been considered "low."

4.7 Effectiveness

A measure of the effectiveness of pollutant-control devices employed in the zinc and related industries can be seen from Table 14, which presents data on the reduction of emissions into the atmosphere of Los Angeles County during the period 1950-1960.

TABLE 14

REDUCTION OF EMISSIONS FROM GALVANIZING AND BRASS-MELTING OPERATIONS, LOS ANGELES COUNTY, 1950-1960[1]

Metal	Melted or Refined (tons per month)	Reduction in Air Pollution Due to Controls (tons per month)	Net Emissions to the Atmosphere (tons per month)
Zinc (except zinc oxide production and galvanizing)	3,000	24	2
Galvanizing (zinc)	600	12	4
Copper and Bronze	1,500	4	1
Red Brass	2,000	3	1
Semi-Red Brass	2,000	18	2
Yellow Brass	1,200	33	2
Totals (rounded)	10,300	124	12

5. ECONOMICS

No information has been found on the economic costs of zinc air pollution or on the costs of its abatement.

Data on the production and consumption of zinc are presented in section 3.

6. METHODS OF ANALYSIS

6.1 Sampling Methods

Dusts and fumes of zinc compounds may be collected by any method suitable for collection of other dusts and fumes; the impinger, electrostatic precipitator, and filters are commonly used. The National Air Sampling Network uses a high volume filtration sampler.

6.2 Quantitative Methods

The ring-oven technique of analysis has been adapted to the determination of zinc in the range 0.05 to 1 $\mu g/m^3$. The reagent, 0-mercaptothenalaniline is used as coloring agent. The method is specific for zinc and may be used in air pollution studies. The limit of detection is 0.04 μg, although previous studies[63] had suggested 0.1 μg as the lower limit.

A spectrophotometric method has been developed for the determination of zinc; concentrations down to 0.1 μg can be measured using 1-(2-thiazolylazo)-2-naphthol.[26]

An instrument capable of monitoring and recording air concentration of zinc sulfide pigment (a phosphorescing tracer) on a real-time basis has been developed. The instrument has a limit of detection of about 0.25 $\mu g/m^3$.[35]

Emission spectroscopy has been used by the National Air Pollution Control Administration for zinc analysis of samples from the National Air Sampling Network.[2] The samples are ashed and extracted to eliminate interfering elements. The minimum detectable zinc concentration by emission spectroscopy is 0.24 $\mu g/m^3$ for urban samples and 0.08 $\mu g/m^3$ for nonurban samples. The difference in sensitivities results from the different extraction procedures required for urban samples.[3]

Thompson et al.[3] have reported that the National Air Pollution Control Administration uses atomic absorption to supplement analyses obtained by emission spectroscopy. The method has a minimum detectable limit of 0.0002 $\mu g/m^3$ based on a 2,000 m^3 air sample.

7. SUMMARY AND CONCLUSIONS

It is not possible to assess fully the role of zinc and its compounds as air pollutants. Despite the fact that specific effects attributed to certain compounds of zinc have been noted, the common association of zinc with other metals, and the frequent presence of toxic contaminants (such as cadmium) in zinc materials, raise questions which have yet to be answered concerning the synergistic effects of these metals.

The most common effects of zinc poisoning in humans are nonfatal metal-fume fever, caused by inhalation of zinc oxide fumes, and illnesses arising from the ingestion of acidic foods prepared in zinc-galvanized containers. Zinc chloride fumes, though only moderately toxic, have produced fatalities in one instance of highly concentrated inhalation. Zinc stearate has been mentioned as a possible cause of pneumonitis. Zinc salts, particularly zinc chloride, produce dermatitis upon contact with the skin.

Accidental poisoning of cattle and horses has occurred from inhalation of a combination of lead- and zinc-contaminated air. Zinc oxide concentrations of 400 to 600 $\mu g/m^3$ are toxic to rats, producing damage to lung and liver, with death resulting in approximately 10 percent of the cases. Although dogs and cats were found to tolerate high concentrations (up to 1,000,000 μg/day) of zinc oxide for long periods, evidence of glycosuria and damage to the pancreas became apparent.

Concentrations of 40,000 to 50,000 μg/m^3 of zinc ammonium sulfate produced no appreciable effects on cats.

Some evidence exists of damage to plants from high concentrations of zinc in association with other metals. No information was found on damage to materials from zinc or its compounds in the atmosphere.

The primary sources of zinc compounds in the atmosphere are the zinc-, lead-, and copper-smelting industries, secondary-processing operations which recover zinc from scrap, brass-alloy manufacturing and reclaiming, and galvanizing processing. Average annual production and consumption of zinc in the United States have increased steadily during this century, and it is predicted that this trend will continue. As the emission of zinc into the atmosphere in most of these operations represents an economic loss of the zinc material, control procedures are normally employed to prevent emission to the atmosphere. In those industries where zinc is a by-product, control procedures for zinc are not as effective, and greater quantities of zinc therefore escape into the environment.

Measurements of the 24-hour average atmospheric concentrations of zinc in primarily urban areas of the United States reveal an average annual value of 0.67 μg/m^3 for the period 1960-1964; the highest value recorded during that period was 58.00 μg/m^3, measured in 1963 at East St. Louis, Ill.

Extensive air pollution abatement methods are in general use by the zinc industry. Control devices include precipitators, scrubbers, baghouses, and collectors. The efficiency of the various control methods varies widely. However, in many instances air pollution control devices are not used in the general metals industries. Thus it is very likely that relatively large quantities of zinc or zinc compounds are emitted into the atmosphere by industrial plants processing zinc or other compounds containing zinc. No information has been found on the economic costs of zinc air pollution or on the costs of its abatement.

Limited means are available for the determination of concentrations of zinc in the ambient air. These methods of analyses, however, are not considered adequate for air pollution monitoring purposes since they do not effectively discriminate between the zinc and other metals and they lack sensitivity.

Based on the material presented in this report, further studies are suggested in the following areas:

(1) Determination of whether zinc acts either as an individual air pollutant exerting specific effects or as a co-pollutant exerting synergistic effects, or has no adverse effects.

(2) Determination of which zinc compounds are present as pollutants in the environmental air, together with the manner in which--and extent to which--these substances affect human, animal, and plant health.

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APPENDIX

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS[66]

Compound	Properties	Toxicity	Uses
Zinc Zn	mp 419.4°C	Inhalation of fumes may result in sweet taste, throat dryness, cough, weakness, generalized aching, chills, fever, nausea, vomiting. Zinc chloride fumes have caused injury to mucous membranes and skin irritation. Ingestion of sol. salts may cause nausea, vomiting, purging	For galvanizing sheet iron; as ingredient of alloys such as bronze, brass, Babbitt metal, German silver, and special alloys for diecasting; as a protective coating for other metals to prevent corrosion; for electrical apparatus, especially dry-cell batteries, for household utensils, castings, printing plates; as building materials, railroad car linings, automotive equipment; as reducing agent in organic chemistry; for deoxidizing bronze; extracting gold by cyanide process, purifying fats for soaps; bleaching bone glue; in manufacture of sodium hydrosulfite insulin zinc salts; as reagent in analytical chemistry (e.g., the March and Gutzeit test for arsenic); as a reducer in the determination of iron
Zinc acetate $Zn(C_2H_3O_2)_2 \cdot 2H_2O$ 35.64%	mp 237°C	Mildly irritating to skin, mucous membranes	For preserving wood; as a mordant in dyeing; in manufacturing glazes for painting on porcelain. As a reagent in testing for albumin, tannin, urobilin, phosphate, blood. Med. use: styptic, astringent, emetic
Zinc arsenate $5ZnO \cdot 2As_2O_5 \cdot 4H_2O$ 34.8%	White, odorless powder	Poison!	
Zinc bacitracin 7%	Creamy powder containing 1-4% H_2O		In ointments, tablets, implantation pellets, suppositories, and troches, either alone or in combination with other antibiotics or therapeutic agents

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc benzoate $Zn(C_7H_5O_2)_2$ 21.25%	Powder. Soluble in 62 parts water at 60°C	The dust can cause respiratory irritation	
Zinc bromide $ZnBr_2$ 29.0%	mp 394°C bp 650°C		In making silver bromide collodion emulsions for photography; in the shielding of viewing windows for nuclear reactions
Zinc caprylate $Zn(C_3H_{15}O_2)_2$ 18.2%	mp 136°C	May liberate irritating fumes of caprylic acid	As fungicide-like zinc propionate
Zinc carbonate hydroxide $5ZnO \cdot 2CO_3 \cdot 4H_2O$ 56% Zn	Odorless powder. Insoluble in water		As pigment; in manufacture of porcelains and pottery. Med. use: has been used topically as antiseptic and astringent
Zinc chromate(VI) hydroxide $Zn_2CrO_4(OH)_2 \cdot H_2O$ 44.0%	Yellow, odorless, fine powder		As pigment in paints, varnishes, oil colors, linoleum, rubber, etc.

(Continued)

APPENDIX

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc chloride $ZnCl_2$ 47.97%	mp 290°C bp 732°C	Moderately irritating to skin	In deodorant, disinfecting and embalming material; alone or with phenol and other antiseptics for preserving railway ties; for fireproofing lumber; with ammonium chloride as flux for soldering; in etching metals; in manufacture of parchment paper, artificial silk, dyes, activated carbon, cold-water glues, vulcanized fiber; in browning steel, galvanizing iron, copperplating iron; in magnesia cements; in petroleum oil refining, cement for metals and for facing stone; as a mordant in printing and dyeing textiles; in carbonizing woolen goods; in producing crepe and crimped fabrics; in mercerizing cotton; in sizing and weighting fabrics; in vulcanizing rubber; in solvent for cellulose; for preserving anatomical specimens; in microscopy for separating silk, wool, and plant fibers; as dehydrating agent in chemical syntheses. Med. use: topically as antiseptic and astringent

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc citrate $Zn_3(C_6H_5O_7)_2 \cdot 2H_2O$ 34.15%	Odorless powder. Slightly soluble in water	Low systemic toxicity. Large doses orally may cause gastrointestinal irritation	
Zinc cyanide $Zn(CN)_2$ 55.68%	White powder. Insoluble in water	Poison!	In electroplating; for removing NH_3 from producer gas
Zinc dichromate (VI) $ZnCr_2O_7 \cdot 3H_2O$ 19.49%	Orange-yellow powder. Soluble in hot water		
Zinc ferrocyanide $Zn_2Fe(CN)_6 \cdot 2H_2O$ 32.96%	White, very hygroscopic leaflets. Soluble in water	No specific data. Probably an irritant	
Zinc fluoride ZnF_2 63.24%	mp 872°C bp 1500°C		In the fluorination of organic compounds, in manufacture of phosphors for fluorescent electric lights; in glazes and enamels for porcelain; for preserving wood; in electroplating baths

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc formate $Zn(HCOO)_2 \cdot 2H_2O$ 34.15%	Crystals. Soluble in water	No specific data. Probably an irritant	
Zinc glycerophosphate $ZnC_3H_5(OH)_2PO_4$ 27.77%	White odorless powder. Water soluble	No specific data See Zinc	
Zinc hexafluorosilicate $ZnSiF_6 \cdot 6H_2O$ 20.72%	White crystals. Soluble in water	Severe corrosive effect on skin, mucous membranes	As mothproofing agent; in laundry sour; as hardener for concrete
Zinc insulin crystals Contains not less than 0.45% nor more than 0.9% Zn	Decomposes between 230-240°C		Med. use: as insulin zinc preparation for diabetes mellitus
Zinc iodate $Zn(IO_3)_2$ 15.75%	White crystalline powder		Med use: has been used as topical antiseptic

(continued)

TABLE 15.PROPERTIES, TOXICITY,AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc iodide ZnI_2 20.48%	mp 446°C bp 625°C		Med. use: has been used as topical astringent, antiseptic
Zinc iodide-starch A soln. prepared by heating 4 parts starch, 20 parts $ZnCl_2$ and 2 ZnI_2 with 1 liter water	Deteriorates with age and acquires a blue color		For detecting nitrites, free Cl, and other oxidizing agents
Zinc lactate $Zn(C_3H_5O_3)_2 \cdot 3H_2O$ 26.85%	Crystals	No specific data See zinc	
Zinc meta-arsenite $Zn(AsO_2)_2$ 23.42%	White powder	Poisonous	Used as a wood preservative; in insecticide
Zinc nitrate $Zn(NO_3)_2 \cdot 6H_2O$ 21.98%	mp 36°C		As a mordant in dyeing

(continued)

TABLE 15·PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc nitride Zn_3N_2 87.50%	Blackish-gray, crystal solid		
Zinc oleate $Zn(C_{18}H_{33}O_2)_2$ 10.4%	White, dry greasy powder. Insoluble in water	No specific data. A case of pneumoconiosis has been reported from related compound, zinc stearate	
Zinc oxalate $ZnC_2O_4 \cdot 2H_2O$ 34.52%	Powder. Very slightly soluble in water	No specific data	
Zinc oxide ZnO 80.34%	Sublimes at normal pressure. Practically insoluble in water	Freshly formed fumes, as from welding, may cause metal-fume fever with chills, tightness in chest, cough and leukocytosis	As pigment in white paints instead of lead carbonate; in cosmetics, driers, quick setting cements; with syrupy phosphoric acid or $ZnCl_2$ in dental cements; in manufacture of opaque glass and certain types of transparent glass; in manufacture of enamels, in automobile tires, white glue, matches, white printing inks, porcelains, zinc green; as a reagent in analytical chemistry. Med. use: as astringent, antiseptic, protective in skin diseases, formerly internally for diarrhea and as an antispasmodic. Dose: ointment, 7.5-20%, paste 25%. Vet use: dressing in moist eczema and on wounds, otorrhea in dogs

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc perchlorate $Zn(ClO_4)_2 \cdot 6H_2O$ 17.56%	mp 106°C Freely soluble in water		
Zinc permanganate $Zn(MnO_4)_2 \cdot 6H_2O$ 15.90%	Violet-brown crystals. Similar to potassium permanganate in appearance. Soluble in 3 parts water		Med. use: 1:4000 soln. as antiseptic and astringent for urethritis
Zinc peroxide ZnO_2 67.14%	White to yellowish-white odorless powder. Decomposes above 150°C		In pharmaceuticals. Med. use: as medicinal zinc peroxide, topically as antiseptic, astringent, deodorant; for wounds and skin diseases. Dose: 40% aq. suspension.
Zinc p-phenolsulfonate $Zn(HOC_6H_4SO_3)_2 \cdot 8H_2O$ 15.88%	Crystals or crystalline powder. Odorless		In insecticide formulations. Med. use: as antiseptic and astringent; has been used as intestinal antiseptic

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc phosphate $Zn(PO_4)_2 \cdot 4H_2O$ 42.81%	White, odorless powder		In dental cements
Zinc phosphide Zn_3P_2 75.99%	mp 420°C bp 1100°C	May liberate phosphine which is highly toxic	In rat and field mice poison preparations
Zinc phosphite $ZnHPO_3 \cdot 2\frac{1}{2}H_2O$ 34.33%	White crystalline powder. Soluble in cold water		
Zinc propionate $Zn(C_3H_5O_2)_2$ 30.91%			As fungicide on adhesive tape to reduce plaster irritation caused by molds, fungi, and bacterial action. Med. use: has been used as antifungoid in dermatology
Zinc pyrophosphate $Zn_2P_2O_7$ 42.91%	White crystalline powder. Insoluble in water		
Zinc salicylate $Zn(C_6H_4(OH)COO)_2 \cdot 3H_2O$ 19.25%	Needles or crystalline powder. Soluble in water		

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc selenate $ZnSeO_4$ 31.38%	Decomposes above 50°C. Soluble in water		
Zinc selenide ZnSe 45.30%	mp 1100°C Decomposes in air. Insoluble in water	Occupational exposure has caused pallor, nervousness, depression, garlic odor of breath and sweat, G.I. disturbances, dermatitis	
Zinc silicate $2ZnO \cdot SiO_2$ 58.68%	White powder		In television screens
Zinc stearate $Zn(C_{18}H_{35}O_2)_2$ 10.34%	mp 120°C	Systemic toxicity negligible. Inhalation may cause pneumonitis	In tablet manufacture; in cosmetic and pharmaceutical powders and ointments; as a flatting and sanding agent in lacquers, as a drying lubricant and dusting agent for rubber; as a plastic mold releasing agent; as a waterproofing agent for concrete, rock wool, paper textiles. Med. and vet. use: as water repellent, desicant, protective agent
Zinc sulfate $ZnSO_4$ 40.50%	Powder or granules. Decomposes above 500°C	Irritating to skin mucous membranes	As a mordant in calico printing; for preserving wood and skins; with hypochlorite for bleaching paper; in manufacture of lithopone and other zinc salts; for clarifying glue, electrodepositing Zn; also as a reagent in analytical chemistry. Med. use: as emetic; externally as astringent or styptic

(continued)

TABLE 15. PROPERTIES, TOXICITY, AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Zinc sulfide $ZnSO_3 \cdot 2H_2O$	White crystalline powder		
Zinc tannate Compound of ZnO and tannin in variable proportions	Yellow, odorless powder		Med. use: formerly as astringent and antiseptic
Zinc tartrate $ZnC_4H_4O_6 \cdot 2H_2O$ 26.21%	Crystalline powder	No specific data	
Zinc telluride ZnTe 33.88%	mp 1239°C	May cause nausea, vomiting, central nervous system depression	In semiconductor research, as a photoconductor
Zinc thiocyanate $Zn(SCN)_2$ 36.02%	White crystals		
Zinc valerate $Zn(C_5H_9O_2)_2 \cdot 2H_2O$ 24.43%	Lustrous scales or powder	No specific data	
Vitamin B_{12}-tannate complex	Practically insoluble in water		Med. use: long-acting injectable vitamin B_{12} preparation

(continued)

TABLE 15.PROPERTIES, TOXICITY,AND USES OF SOME ZINC COMPOUNDS (Continued)

Compound	Properties	Toxicity	Uses
Undecylenic acid, zinc salt $Zn(C_{11}H_{20}O_2)_2$	Amorphous white powder		Med. use: as topical fungistatic agent. Has been given orally. Vet. use: in cutaneous fungus infections, such as ringworm

TABLE 16

PHYSICOCHEMICAL PROPERTIES OF ZINC[30]

Atomic weight:	65.37
Atomic number:	30
Valence:	+2
Specific gravity:	7.13 g/cm^3
Melting point:	419.5°C
Boiling point:	906°C

Grades of Slab Zinc	% Pure Zinc
Special high grade	99.99
High grade	99.90
Intermediate	99.50
Brass special	99.00
Selected	98.75
Prime western	98.30

TABLE 17

PRIMARY AND REDISTILLED SECONDARY SLAB ZINC PRODUCED IN THE UNITED STATES[32]

(Short Tons)

Type of Zinc	1963	1964	1965	1966	1967
Primary:					
From domestic ores	474,007	531,967	551,215	523,580	438,553
From foreign ores	418,577	422,117	443,187	501,486	500,277
Total	892,584	954,084	994,402	1,025,066	938,830
Redistilled secondary	60,303	71,596	83,619	83,263	73,505
Total*	952,887	1,025,680	1,078,021	1,108,329	1,012,335

*Excludes zinc recovered by remelting.

TABLE 18

CONSUMPTION OF ZINC IN THE UNITED STATES[32]
(Short Tons)

Type of Zinc	1963	1964	1965	1966	1967
Slab zinc	1,105,113	1,207,268	1,354,092	1,410,197	1,236,808
Ores (recoverable zinc content)	104,705[a]	105,948[a]	122,892[a]	126,696[a]	114,301[a]
Secondary (recoverable zinc content)[b]	204,398	222,535	265,083	269,650	240,888
Total	1,414,216	1,535,751	1,742,067	1,806,543	1,591,997

[a] Includes ore used directly in galvanizing.

[b] Excludes redistilled slab and remelt zinc.

TABLE 19

MANUFACTURERS OF ZINC SLAB IN THE UNITED STATES, 1968[54]

Company	Location
Aluminum Smelters Inc.	New Haven, Conn.
American Metal Climax Inc.	New York, N.Y.
American Smelting and Refining Co., Federated Metals Div.	New York, N.Y.
American Zinc	St. Louis, Mo.
Anaconda Company	New York, N.Y.
Anchor Alloys Inc.	Brooklyn, N.Y.
Arco Die Cast & Metals Inc.	Detroit, Mich.
Associated Metals & Minerals Corp.	New York, N.Y.
Bay State Smelting Corp.	Somerville, Mass.
Behr, Joseph & Sons, Inc.	Rockford, Ill.
Belmont Smelting & Refining Works	Brooklyn, N.Y.
Bullock, W. J., Inc.	Fairfield, Ala.
Car-Mor Metal Co.	Wilmington, Del.
Cassell, Adam A., Metal Co.	Milwaukee, Wis.
Certified Metals Mfg. Co.	Cincinnati, Ohio
City Metals Refining Co.	Detroit, Mich.
Combined Metals Reduction Co.	Salt Lake City, Utah
Eagle-Picher Industries Inc.	Cincinnati, Ohio
Empire Metal Co.	Syracuse, N.Y.
General Smelting Co.	Philadelphia, Pa.
Hayman, Michael, & Co., Inc.	Buffalo, N.Y.
Henning Bros. & Smith Inc.	Brooklyn, N.Y.
Illinois Smelting & Refining Co.	Chicago, Ill.
International Minerals & Metals	New York, N.Y.
Jordan Company	Chicago, Ill.
Kahn Bros. Smelting Corp.	Brooklyn, N.Y.
Kirk, Morris P., & Son	Los Angeles, Calif.
Lapides Metals Corp.	New Haven, Conn.
Matthiessen & Hegeler Zinc Co.	La Salle, Ill.
Metal Corrosion Control	Plainfield, N.J.
Metallurgical Products Co.	Philadelphia, Pa.
Michigan Standard Alloys Inc.	Benton Harbor, Mich.
National Lead Co., Metal Div.	New York, N.Y.
National Zinc Co.	New York, N.Y.
New England Smelting Works Inc.	West Springfield, Mass.
New Jersey Zinc Co.	New York, N.Y.
Ney Metals Inc.	Long Island City, N.Y.
North American Smelting Co.	Wilmington, Del.
Pacific Smelting Corp.	Torrance, Calif.
Pitt Metals Co.	Pittsburgh, Pa.
Republic Metal Co.	Brooklyn, N.Y.
St. Joseph Lead Co.	New York, N.Y.
Sandoval Zinc Co.	Chicago, Ill.
Seitzinger's Inc.	Atlanta, Ga.
Smith & McCrorken	New York, N.Y.
Star Refining Co.	Boston, Mass.
United States Smelting Works	Philadelphia, Pa.
Viener, Hyman & Sons	Richmond, Va.

TABLE 20

PRIMARY SLAB ZINC PLANTS BY GROUP CAPACITY IN THE UNITED STATES IN 1967[32]

Type of Plant	Plant Location	Slab Zinc Capacity (Short Tons)
Electrolytic plants:		525,000
American Smelting and Refining Company	Corpus Christi, Tex.	
American Zinc Company of Illinois	Sauget, Ill.	
The Anaconda Company	Anaconda, Mont.	
The Anaconda Company	Great Falls, Mont.	
The Bunker Hill Company	Kellogg, Idaho	
Horizontal-retort plants:		742,500
American Smelting and Refining Company	Amarillo, Tex.	
American Zinc Company of Illinois	Dumas, Tex.	
Blackwell Zinc Company, Division of American Metal Climax, Inc.	Blackwell, Okla.	
Eagle-Picher Industries, Inc.	Henryetta, Okla.	
Matthiessen & Hegeler Zinc Company*	LaSalle, Ill.	
National Zinc Company	Bartlesville, Okla.	
Vertical-retort plants:		
Matthiessen & Hegeler Zinc Company	Meadowbrook, W. Va.	
The New Jersey Zinc Company	Depue, Ill.	
The New Jersey Zinc Company	Palmerton, Pa.	
St. Joseph Lead Company	Josephtown, Pa.	

*Plant closed July 1, 1961.

TABLE 21

SECONDARY SLAB ZINC PLANTS BY GROUP CAPACITY IN THE UNITED STATES IN 1967[32]

Company	Plant Location	Slab Zinc Capacity (Short Tons)
American Smelting and Refining Company	Sand Springs, Okla.	
American Smelting and Refining Company	Trenton, N.J.	
American Zinc Company of Illinois	Hillsboro, Ill.	
Apex Smelting Company	Chicago, Ill.	
Arco Die Cast Metals Company	Detroit, Mich.	
W. J. Bullock, Inc.	Fairfield, Ala.	
General Smelting Company	Bristol, Pa.	55,900
Gulf Reduction Company	Houston, Texas	
H. Kramer Company	El Segundo, Calif.	
Pacific Smelting Company	Torrance, Calif.	
Sandoval Zinc Company	Sandoval, Ill.	
Superior Zinc Corporation	Bristol, Pa.	
Wheeling Steel Corporation	Martins Ferry, Ohio	

TABLE 22

CONCENTRATION OF ZINC IN THE AIR[67-69]

Location	Micrograms per cubic meter											
	1954-59[a]		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
Alabama												
Birmingham	8.40	1.29									8.60	1.00
Arizona												
Phoenix							1.60	0.55			1.50	0.33
California												
Los Angeles	2.00	0.72			1.50	0.59	1.80	0.67	1.80	0.39		
San Francisco							2.10	0.34	1.10	0.15		
Colorado												
Denver	1.40	0.30					1.40	0.53	1.50	0.52	1.90	0.22
D.C.												
Washington							1.40	0.26	0.65	0.26	0.65	0.05
Georgia												
Atlanta	7.90	0.88					12.00[b]	3.52[b]	6.40	1.28		
Idaho												
Boise			0.43	0.14			0.33	0.01			0.23	0.01
Illinois												
Chicago	2.40	0.93			7.20	1.56	4.00[b]	0.95[b]	5.50	1.52	3.80	0.95
Cicero							4.60	1.16				
E.St.Louis									58.00	5.52		
Indiana												
E. Chicago											12.00	2.57
Indianapolis	1.10	0.18			1.00	0.52	1.20	0.28				

TABLE 22 (Continued)

CONCENTRATION OF ZINC IN THE AIR

Location	Micrograms per cubic meter											
	1954-59[a]		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
Iowa												
Des Moines	0.79	0.04	1.60	0.57			0.82	0.16			0.00	
Louisiana												
New Orleans	0.65	0.09					0.36	0.03	0.00[b]			
Maryland												
Baltimore	2.00	0.63			2.20	0.59	1.60	0.41			2.50	0.61
Massachusetts												
Boston	6.90	0.73									0.79	0.33
Michigan												
Detroit	1.80	0.50					1.80	0.72	1.70	0.41	4.30	0.83
Missouri												
St. Louis	8.20	1.61					5.50	1.53	3.00	0.69	4.10	0.67
Montana												
Helena											0.43	0.05
Nevada												
Las Vegas							0.00		0.31	0.01	0.00	
New Jersey												
Newark					4.50	0.70	4.60	0.82			3.30	0.64
New York												
Buffalo							1.90	0.38	1.80[b]	0.43[b]		
New York							2.80	0.86	2.10	0.78	1.80	0.49

TABLE 22 (Continued)

CONCENTRATION OF ZINC IN THE AIR

Location	Micrograms per cubic meter											
	1954-59a		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
No. Carolina												
Charlotte	0.92	0.23									0.46	0.08
Winston-Salem							0.75	0.27				
Ohio												
Cincinnati			17.00	2.56			15.00	2.05	8.00	1.62	14.00	2.87
Cleveland	2.70	0.81					4.20	0.85	2.60	0.95	2.10	0.65
Columbus							0.32	0.02				
Dayton	1.60	0.56										
Pennsylvania												
Allentown					5.90	1.17						
Philadelphia	1.40	0.63	8.20	1.95			7.00	1.47	5.00	1.14	6.10	1.41
Pittsburgh	4.50	1.09					7.30	1.12	20.00	2.22	8.00	1.06
Scranton					0.99	0.42						
Tennessee												
Chattanooga											2.10	0.57
Nashville	1.00	0.25										
Texas												
El Paso							2.90	1.12	3.60	1.21	3.60	1.16
Houston	2.50	0.28										
Washington												
Seattle	1.70	0.81					0.57	0.15	0.71	0.11	0.71	0.13
Tacoma	0.75	0.11					0.47	0.08	0.00		0.47	0.04

TABLE 22 (Continued)

CONCENTRATION OF ZINC IN THE AIR

Location	Micrograms per cubic meter											
	1954-59[a]		1960		1961		1962		1963		1964	
	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg	Max	Avg
West Virginia Charleston											0.62	0.07
Wisconsin Milwaukee	1.40	0.40									1.00	0.16
Wyoming Cheyenne	0.86	0.03									0.00	
Nebraska Omaha	1.70	0.47					0.83	0.13				
Florida Tampa	0.96	0.14										
Kansas Wichita	1.10	0.64										
New Hampshire Manchester	0.69	0.08										
North Dakota Bismarck	0.48	0.01										
Oregon Portland	4.10	0.67										
Utah Salt Lake City	0.90	0.03										

[a] Data for 1954-59 include the averages for all measurements during this period, or only one-year values, as available.

[b] Partial year only.